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a attenuation means for reducing and/or homogenizing the ion flux from the plasma substantially without affecting the neutral radical number density.

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21. (Twice Amended) A plasma processing apparatus according to claim 1, wherein the attenuation means is designed to produce a high magnetic field  
B2 capable of significantly reducing the ion flux during the etch step.

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### REMARKS

#### *Summary*

By this Amendment, Claims 2 and 26-28 have been canceled, and Claims 1 and 21 have been amended. Accordingly, among the elected claims, Claims 1, 4, 6-10, 12-15 and 21 remain pending in the application.

#### *Specification*

By this Amendment, an abstract on a separate sheet is submitted as required by the Examiner. Also, by this Amendment, a substitute specification is submitted to adopt American-style English spellings and to correct minor informalities as required by the Examiner.

No new matter has been added.

***Claim Objections***

By this Amendment, Claim 1 has been revised to adopt the American-style English spelling of "homogenizing" as required by the Examiner.

The objection to Claim 27 has been rendered moot by the cancellation thereof.

***35 U.S.C. ¶112, second paragraph***

By the Amendment, Claim 1 has been revised to insert "neutral" before -- radical -- , and Claim 21 has been revised to insert "magnetic" before -- field -- , as suggested by the Examiner. It is thus believed that the rejections under 35 U.S.C. ¶112, second paragraph, have been overcome.

***35 U.S.C. ¶102 and ¶103***

Claims 1, 2, 4, 6 and 26 were rejected under 35 U.S.C. ¶102 as being unpatentable over Amemiya et al (EP 0488393 A2) for the reasons stated at pages 3-4 of the Office Action. Claims 1, 2, 4, 6-9, 12, 13-15, 21 and 26-28 were rejected under 35 U.S.C. ¶102 or ¶103 as being unpatentable over Ohkawa et al. (EP 0831516 A2), taken alone or in combination with Kin (JP 61-39521), Ribeiro (US 4,769,101) or Maeno et al. (US 6,060,836) for the reasons stated at pages 4-7 of the Office Action. However, Applicants respectfully contend that the now-

pending claims define over the cited references, and in view of the following representations, reconsideration of the rejections under 35 U.S.C. ¶102 and ¶103 is requested.

By this Amendment, Claim 1 has been amended to clarify that the apparatus of the invention is of the type which is configured to alternately and repeatedly effect etching and deposition processes. As explained in the present specification, such apparatus allows for the formation of trenches having high aspect ratios. However, as also explained in the specification, the conditions ideal for the etching step may not be ideal for the deposition (passivation) step. The attenuation means, which reduces and/or homogenizes the ion flux from the plasma substantially without affecting the radical number density, is provided at least in part to compensate for the differing operational conditions of the alternating etching and deposition processes of the apparatus. Please see pages 1-3 of the present specification.

The Examiner seems to suggest that the original Claim 2 was unpatentable because the apparatus of Amemiya et al and Ohkawa et al. can allegedly be used for etching as well as for deposition. Even if this were so, the apparatus of the references are clearly designed for use in such a way that only one process can be operated at any one time. The references have not considered the concept of

alternating etch and deposition processes, and the references do not disclose apparatus which are suitable for alternating etch and deposition processes.

The cited references, taken individually or in combination, do not teach or suggest an apparatus for alternating effecting etch and deposition process which is additionally equipped with an attenuation means for reducing and/or homogenizing the ion flux from a plasma substantially without affecting the neutral radical number density.

For at least the reasons stated above, Applicant's respectfully contend that the now pending claims define over the cited references, taken individually or in combination.

***Conclusion***

No other issues remaining, reconsideration and favorable action upon the claims now-pending in the application are requested.

Respectfully submitted,

JYOTI KIRON BHARDWAJ ET AL.

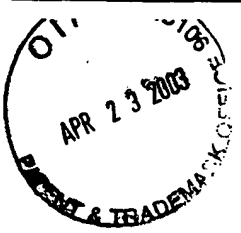
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## ABSTRACT OF THE DISCLOSURE

B<sup>2</sup> A plasma processing apparatus includes a chamber having a support for a substrate, and at least one gas inlet into the chamber. The apparatus is configured to alternately introduce an etch gas and a deposition gas into the chamber through the at least one gas inlet, and to strike a plasma into the etch gas and the deposition gas alternately introduced into the chamber. The apparatus is further equipped with an attenuation device for reducing and/or homogenizing the ion flux from the plasma substantially without affecting the neutral radical number density.

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ATTACHMENT "A"

1. (Amended) A plasma processing apparatus comprising:

a chamber having a support for a substrate;

at least one gas inlet into the chamber;

means for alternately and repeatedly introducing an etch gas and a deposition gas into the chamber through the at least one gas inlet, wherein the deposition gas is different than the etch gas;

means for striking a plasma into the etch gas and the deposition gas alternately introduced into [in-a] the chamber [having a gas inlet and a support for a substrate, wherein the apparatus further comprises];

attenuation means for reducing and/or [homogenising] homogenizing the ion flux from the plasma substantially without affecting the neutral radical number density.

21. (Twice Amended) A plasma processing apparatus according to claim 1, wherein the attenuation means is designed to produce a high magnetic field capable of significantly reducing the ion flux during the etch step.

## ATTACHMENT "B"

Plasma Processing Apparatus

This invention relates to a plasma processing apparatus, in particular, although not exclusively, one for reducing and/or homogenizing the ion flux of a plasma without affecting the radical number density of the plasma. The invention also relates to means for reducing and/or homogenizing the ion flux and means for guiding neutral radicals.

When etching thin films or bulk material on a silicon wafer or work pieces of other material, it is important to be able to achieve simultaneously a high etch rate, an accurate trench profile, and good uniformity of the etch between different areas of the wafer.

A particular method to achieve highly anisotropic etches for high aspect ratio trenches is to use a switched process in which an etch step is alternated with a deposition step. Such a method is disclosed in WO-A-94/14187, EP-A-0822582 and EP-A-0822584.

In the case of deep trench silicon etching, a passivating layer may be deposited on all surfaces of the trench, during the deposition step. During the initial part of the etch step, the passivating layer will be removed preferentially from the bottom of the trench by ion bombardment. This then allows the silicon to be removed by an essentially chemical process, from the bottom of the trench, during the remainder of the etch step. Alternating deposition and etch steps, allows a high aspect ratio trench



to be etched, ~~subsequent~~ contrasting with the use of the etch step alone which would result in a predominantly isotropic etch.

There are a number of factors which will influence each step of the deep etch process. In particular, during the  
5 etch step, the density of radicals will affect the rate of etch of exposed silicon, and the density, energy and direction of positive ions will affect where and how fast the passivating layer is removed.

For deep trench etching it is desirable to utilize<sup>7</sup> a  
10 plasma processing apparatus which produces large numbers of radicals to achieve a high silicon etch rate. Indeed, conditions ideal for the etching step may not be ideal for the passivation step. At the same time, sufficient numbers of very directional, relatively low energy ions should be  
15 produced to remove the passivating layer from the bottom of the trench without at the same time removing a significant thickness of the photoresist mask. Clearly, once the mask has been etched away it is not possible to continue with the same degree of pattern transfer from the mask.

20 A plasma processing apparatus will produce both ions and radicals and the number of each will, in general, increase as the power input into the apparatus is increased. The relative numbers of radicals and ions may change with power input conditions, but will not necessarily be the  
25 ideal balance required for the deep trench etch.

The present invention, at least in some embodiments, discloses techniques and devices to adjust the balance of numbers, to modify spatial distributions and allow

"discrete" <sup>z</sup>optimisation of both steps (etch and passivation), to ensure the etching of accurate trench profiles, with good uniformity of etch between different areas of the wafer. Methods of largely "decoupling" the generation of the etch species from that of the passivation species are presented. Indeed, the invention is applicable to all plasma processes where this may be beneficial.

According to a first aspect of the present invention, there is provided a plasma processing apparatus comprising means for striking a plasma in a chamber having a gas inlet and a support for a substrate, wherein the apparatus further comprises attenuation means for reducing and/or homogenising<sup>z</sup> the ion flux from the plasma substantially without affecting the radical number density.

The substrate support, and substrate may be electrically biased~~x~~ as appropriate to the process.

The attenuation means may extend partially or completely across the chamber.

A plasma processing apparatus may refer to an apparatus in which the process plasma is created and maintained by the inductive coupling of RF power into it, and bias is applied to the substrate (which may be a wafer/workpiece) by a second RF power source. However, this description is for the purpose of explaining the concepts involved, and is not intended to preclude apparatus in which plasma is generated by other means such as microwave, ECR, Helicon, Capacitive, DC, and pulsed power discharges etc, nor to preclude apparatus in which bias is applied to the substrate by DC or

RF means whether pulsed or not.

5 The plasma processing apparatus may be used in a continuous or switched process with an attenuation means that may be changed in strength for each of the deposition and/or etch steps in a cyclic etch/deposition process.

The attenuation means may be any suitable attenuator or filter, and particular preferred examples are described below.

10 The plasma processing apparatus may further comprise means for providing alternating etch and deposition steps. The etch and deposition gases may be fed via the same or separate distribution systems.

15 Whilst  $\text{SF}_6$  is used as an example of the etch gas, other etch gases may be used, and these are well known to those skilled in the art.

20 In a preferred embodiment, at least a portion of the chamber is formed of a dielectric material. Particularly, it is preferred that an upper part of the chamber is formed of a dielectric material, where the substrate support is in the lower part of the chamber. Preferably, an antenna is positioned externally adjacent the dielectric portion and this may serve to create a plasma production region in the chamber. The antenna may be used to inductively couple RF power into the plasma which is formed inside the apparatus.

25 The frequency of the RF power is typically 13.56 MHz, but other frequencies may also be used.

The substrate support is preferably energised from a second RF supply. It is well known by those familiar with

to create respective magnetic fields which are angularly offset with respect to one another. Advantageously three sets of coil groups are provided which are designed to create magnetic fields which are offset from one another by 60 degrees or 180 degrees. These can be energised in sequence to create a rotational field. Where the coils have the 60 degree offset, a full 360 degree rotational effect can be achieved by reversing the polarity of the power supply after an initial sequence of energisations of the three groups has taken place.

If desired the attenuation means may comprise both one or more permanent magnets and means for creating an electromagnetic field so that a chosen proportion of the field strength is constant from the permanent magnets, but may be increased or decreased by altering the current creating the electromagnetic field. As the electromagnetic field is only a proportion of the total field, the required current will be reduced when compared with that needed to create a total field, leading to a requirement for a smaller power supply and smaller cross-section conductors. This provides the possibility of, for example, making use of the attenuation during the etch step of a switched process, but reducing or switching off the field entirely during the deposition step. In fact the magnetic attenuation/filter strength can become a process variable, altered between steps of a switched process, or varied during the course of a non-switched process, or varied during the course of a switched process, or both altered between steps of a

positioned therebetween. This allows a more practicable means of electrically biasing the sheet member and the general concept is also transferable to other geometries of the process apparatus.

5 Two or more antennae may be positioned externally adjacent the dielectric portion or portions and at least one antenna preferably lies above the level of the attenuation means, and at least one antenna lies below the level of the attenuation means. In such an embodiment, the chamber may  
10 be provided with an inlet to provide a gas or gases above the level of the attenuation means and a further inlet for providing a gas or gases below the level of the attenuation means. In particular the further antenna (or other means for striking a plasma) below the attenuation means may be  
15 provided for the deposition step of an etch/deposition process. Thus, where a further antenna is below the attenuation means, gas may be provided below the level of the attenuation means.

According to a further aspect of the present invention,  
20 there is provided an attenuation means for use in a plasma processing apparatus having means for striking a plasma in a chamber, wherein the attenuation means is capable of reducing and/or homogenising<sup>Z</sup> the ion flux from the plasma substantially without affecting the radical number density.

25 The attenuation means may have the preferred or optional features mentioned above.

To etch a substrate with a switched process, as described previously, the attenuation means may be used to

means for striking a plasma in a chamber having a gas inlet and a support for a substrate, wherein the apparatus further comprises a guiding means.

According to a further aspect of the present invention,  
5 there is provided a method of etching a feature in a substrate in a chamber, the method comprising striking a plasma in the chamber and reducing and/or homogenising the ion flux from the plasma substantially without affecting the radical number density. The method may comprise the step of  
10 alternately etching the substrate and depositing a passivation layer on the substrate.

According to a further aspect of the present invention,  
there is provided a method of etching a feature in a substrate in a chamber, the method comprising alternately  
15 etching the substrate and depositing a passivation layer on the substrate, wherein neutral radicals during the etch step are guided by a guiding means to improve the uniformity of etching across the substrate.

For high etch rates, the number of radicals needs to be  
20 increased, and this may be achieved in a number of ways:  
(a) By increasing the source power, the precursor gas dissociation fraction is increased. For example,  $\text{SF}_6 \rightarrow \text{SF}_x + y\text{F}$ . However, the efficiency is limited in terms of the number of fluorine radicals released from each  $\text{SF}_6$  molecule,  
25 i.e. two fluorine radicals are readily liberated. However, the stability of the dissociates and recombination reactions limit release of more than two fluorine radicals from each  $\text{SF}_6$  molecule. Even so, the etch rate can be significantly

substrate and depositing a passivation layer on the substrate in a chamber.

The high power is preferably applied for between 100 microseconds and several milliseconds during each pulsed cycle. In a preferred embodiment, the power density of the pulsed high power is between 10 and 300 W/cm<sup>2</sup>.

The method may further comprise the step of reducing and/or homogenising the ion flux from the plasma substantially without affecting the radical number density and, for example, any of the above-mentioned methods can be used. The method may additionally, or alternatively, comprise the step of guiding neutral radicals.

According to a further aspect of the present invention, there is provided a plasma processing apparatus for performing the above method, the apparatus comprising a first chamber having an inlet for an etch source gas and a second chamber having a support for a substrate, wherein the first and second chambers are connected via an aperture, and wherein the apparatus further comprises a means for providing pulsed high power to the first chamber.

The pulsed high power discussed below is RF, but any power may be used, for example microwave or DC.

In one embodiment, the first chamber may comprise a dielectric window and the means for introducing the RF pulsed high power is an antenna which is preferably positioned externally adjacent the dielectric window.

The second chamber may be actually separated by a separating member from the first chamber and indeed more

than one first chamber providing a pulsed source may be used.

The second chamber may have a separate gas inlet.

Preferably, the plasma processing apparatus further  
5 comprises attenuation means which may be in the region of the aperture. This attenuation means may be the same as the forms mentioned above, but is preferably in the form of magnets placed on either side of the aperture to form a magnetic filter. This improves the confinement of the  
10 pulsed plasma within the source. Alternatively, magnets may be located in tubes across the aperture in, for example, a similar configuration to that described above.

In one embodiment, a restricted conductance aperture connects the first and second chambers which allows a higher  
15 source pressure to be practically utilised.

According to a further aspect of the present invention, there is provided a method of etching a feature in a substrate, the method comprising applying a high density radical source to an etch source gas, and alternately  
20 etching the substrate and depositing a passivation layer on the substrate in a chamber.

The etch and/or deposition steps preferably take place by means of a plasma.

Although the invention has been defined above, it is to  
25 be understood that it includes any inventive combination of the features set out above or in the following description.

The invention may be performed in various ways and various specific embodiments thereof will now be described,



Figure 12B is an enlarged view of part of Figure 12A;

Figure 13 is an alternative apparatus incorporating a guiding means;

Figure 14 shows experimental measurements of positive ion current density, obtained using attenuation means of the form shown in Figures 1 and 2;

Figure 15 shows experimental measurements at various powers;

Figures 16A and B show an electromagnetic coil design; and

Figure 17A, 17B and 17C <sup>show particular</sup> ~~show particular~~ features of a preferred electromagnetic coil attenuator structure.

Referring to Figure 1, there is shown a plasma processing apparatus generally at 1. The apparatus 1 comprises a chamber 2 into which an etch or deposition gas (or both) may be passed through inlet 3 in its lid 4. Extending through the base 5 of the chamber 2 is a platen 6 on which is mounted a wafer 7, for example a semiconductor wafer. The chamber 2 has a side wall 8, the upper region of which is formed as a dielectric window 9. An antenna 10 is located outside of the dielectric window 9 and is used to couple RF power inductively into the plasma which is formed inside the apparatus. The frequency of the RF power is 13.56 MHz, but other frequencies may also be used. In using the embodiment shown, in use etch and deposition gases are fed alternately through the inlet 3, depending on which of the etch or deposition steps is in progress. The platen 6

is energized<sup>7</sup> from a second RF supply.

Within chamber 2, a series of parallel tubes 11 are mounted in a plane parallel to the surface of the platen 6. Each tube contains a small permanent magnet or series of  
5 magnets arranged as shown in Figure 2. Forced air, water or other suitable cooling medium is passed through the tubes to ensure that the magnets are not subjected to high temperatures. The cooling medium is distributed by means of a manifold 13.

10 In an alternative form, the permanent magnets 12 may be replaced by current carrying conductors in tubes arranged, as mentioned above, in such a way as to create electro-magnetic fields of similar strengths and orientations to those achieved by the permanent magnets. As a further  
15 variant, the use of a hybrid of permanent magnets and electromagnets is also envisaged. The principle of operation is that electrons from the plasma created near the antenna 10 move into the region of influence of the magnetic field, are guided by the magnetic field and lost to the wall  
20 8 or manifold 13 due to an  $E \times B$  drift. The electric field set up in the plasma by the loss of electrons ensures that ions are also attracted to the wall or manifold where they too are lost. The net result is a reduction in plasma density, on transmitting the magnetic field, from the region  
25 in which the plasma is produced to the region in which the wafer is placed. The magnetic field has no effect on the radicals, and the magnet carrying tubes have only marginal effect on the radical numbers due to a small degree of

combination of both.

Figure 6 shows an alternative arrangement in which a horizontally disposed grid 18 is located across the chamber 2, separating the plasma production region, adjacent to the dielectric window 9, from the wafer 7. The grid 18 has apertures 19 of varying sizes at different positions and may have solid sections with no apertures. The effect of the grid 18 is to attenuate the ion flux reaching the wafer due to ion loss on the grid 18, as described above.

Figure 7 shows a variation of the design described with reference to Figure 6. In this embodiment, <sup>a</sup>grid ~~X~~ 20 having apertures 21 is of cylindrical form (for a cylindrical process chamber). Gas may be fed in at either or both of inlet 3 or the second inlet 3A depending on whether a deposition step or an etch step is in progress. Similarly to the system as described with reference to Figure 3, the grid 20 may or may not extend all the way from the lid 4 to the bottom of the dielectric window 9.

A more complex form of the plasma processing apparatus is shown in Figure 8. A grid 18 is located part way down a dielectric window 22. The grid 18 may be supported from the lid 4 or from below the dielectric window 22. As proposed above, the grid 18 may have a number of identical apertures in it or may have sections additionally having larger apertures or sections which are blanked off with the aim of producing spatial improvements in the uniformity of the overall etch at various positions on the wafer 7. Two antennae 23, 24 are wound around dielectric window 22,

antenna 23 being positioned above the level of grid 18 and an antenna 24 being positioned below it. Gas is fed through inlet 3 to the chamber and a further gas inlet 25 feeds a gas ring 26 or similar gas distribution device located below grid structure 18. As before, the wafer 7 is supported on a platen 6 near the bottom of the chamber.

With the similar plasma processing chambers shown in Figures 6 and 7, passivating material may be deposited on the grid structure during the deposition step. This effect may be reduced by ensuring that the grid structure is heated, but there may still be a need for enhanced passivation when the grid structure is present.

For the apparatus shown in Figure 8, the preferred method of operation is as follows. For the etch step, gas is fed into inlet 3 and antenna 23 is energised. Radicals pass through the grid structure 18 down to the surface of the wafer 7, while the positive ions are attenuated and their spatial distribution modified by the grid structure. If found to be of benefit, antenna 24 may also be energised at a low power level, and some gas used in the etch step may be introduced through gas inlet 25. For the deposition step, the appropriate gas is fed to gas inlet 25, and antenna 24 is energised. It would not normally be necessary to energise antenna 23 or feed gas into inlet 3 during the deposition step of the process.

For the apparatus shown in Figure 8, the grid structure 18 may be replaced by a magnetic attenuator of any of the forms previously described, with the operating scenario

above. The subsidiary chamber 28, dielectric side walls 29, antenna 30 and inlet 31 together form a high power pulsed source generally shown at 33. The aim is to produce copious numbers of radicals within the pulsed source 33 which then  
5 diffuse into the main process chamber. In order to improve the confinement of the pulsed plasma within the source, magnets 34 are positioned either side of the aperture 27 to form a magnetic filter. Alternatively, magnets may be located in tubes across the aperture in a similar  
10 configuration to that shown in Figures 1 and 2, for example, for dividing the main process chamber 2.

Figure 10 shows an alternative embodiment in the region of the aperture 27. In this embodiment, the lower portion of the subsidiary chamber comprises walls 35 which converge  
15 at their upper end opposite the end at aperture 27. Although the Figure shows tapering of the dielectric section, this section may alternatively ~~may~~ be of metallic construction, possibly as an extension of the separating member structure. This provides a low pumping conductance  
20 aperture and, in such an embodiment, the pressure in the pulsed high power plasma source may be increased without having a detrimental effect on the pressure in the main process chamber 2.

The aim of the embodiments presented in Figures 9 and  
25 10 is to create a high radical density source which can provide a means for carrying out the etching step while the deposition plasma source is separated. The high pulsed power source presented above can be replaced by any high

The isolated conducting material or the ~~or~~ dielectric material will attain the floating potential of the local plasma as a balance occurs between the fluxes of ions and electrons reaching it. Other ions will pass through the aperture(s) in the disc 36, or around it, to reach the substrate.

Figure 12A shows an alternatively shaped guiding means 37, which encourages a pressure or flow gradient across the wafer 7. However, an even more complex geometry (with apertures if necessary) may be used, depending on the substrate and etch pattern shape, reactor design and local pressure and gas flow behaviour. Figure 12B shows an enlarged view of part of Figure 12A intended to overcome the excess radical flux to the edge of wafer 7, as described above. The shaped guiding means 37 has a portion 37A parallel to the wafer 7 and an inclined portion 37B. The inclined portion 37B provides increasing flux to the surface of wafer 7 - without this, the "edge effect" may occur with respect to the inside edge of the guiding means. In the embodiment shown, dimension d is small, so that the edge of portion 37A is close to the edge of wafer 7. Dimensions a, c and d can be adjusted as necessary to compensate for edge effects.

The guiding means may be installed in a process chamber which <sup>2</sup>utilises a de-coupled plasma source, for example as shown in Figure 13. The guiding structure is shown at 38. Antenna 39 is used to strike and maintain the relatively high power plasma for the etch step, utilising gas from a

first gas distribution system through inlet 3. This intense discharge leads to the creation of large numbers of radicals, which diffuse towards the wafer 7 and are guided to the wafer surface by the guide structure 38. The high ion flux from the discharge is reduced by the attenuation structure 40 to an appropriate level for the process.

For the deposition step, gas may be introduced either above or below the attenuation structure 40, through inlet 3, or through inlet 41 linked to a second gas distribution system. Antenna 42 may be used to produce a plasma of suitable density for the deposition process. With this scenario, for the deposition step, antenna 39 would not normally be energized. An alternative arrangement in which antenna 42 is not fitted on the apparatus, would utilize a plasma struck and maintained by antenna 39 utilising the appropriate deposition gas, or alternative gas, fed via gas distribution systems. Deposition gas would be introduced through inlet 41. In either case the deposition material diffuses down to the guide structure 38, where it is guided to the surface of the wafer 7.

The guiding structure may also be used in the apparatus shown in Figure 9 in which large numbers of radicals are produced in a separate chamber. The purpose of the guiding structure, however, remains the same as described above.

The guiding structure may be heated to reduce the deposition on it.

Figure 14 shows the results from three sets of experimental measurements of positive ion current density

contact with the plasma by a structure which has high transparency to the passage of neutrals. The arrangement of the number of coils is such that groups of them are connected together. At a given time one or more groups may  
5 be energised<sup>z</sup>, providing a magnetic field across the processing chamber 47, which attenuates the flux of ions reaching the substrate 48, while offering minimal obstruction to the passage of neutrals.

The location of the coils that produce the magnetic  
10 field, within the processing chamber, allows a field to be produced that is localised<sup>z</sup> in the vertical direction i.e. does not extend greatly into the high-density plasma region 49, or down towards the substrate 48. This is achieved because the coils can be spaced a few tens of mm apart so  
15 that the field is localised<sup>z</sup> to a distance of this order in the vertical direction. This is in contrast to placing coils or permanent magnets outside of the processing chamber, when the magnetic field will extend of the order of hundreds of mm in the vertical direction, because the coils  
20 or permanent magnets are spaced hundreds of mm apart. A long range field extending into the high density plasma region may reduce the effectiveness with which power is coupled into the plasma, while a significant field strength at the substrate surface may affect the directionality of  
25 ions which reach the substrate.

The groups of coils have their terminations brought out of the processing chamber via suitable feedthroughs that are compatible with the vacuum properties required in the



chamber. Fluid or gas may be circulated around the coils to remove the heat produced by ohmic heating of the wire and the heat transferred to the structure surrounding the coils, by the plasma. The structure surrounding the coils must be  
5 constructed such as to prevent the fluid or gas from escaping into the processing chamber and further feedthroughs may need to be installed for introducing the fluid or gas. A group of coils is energised<sup>Z</sup> by the connection of a power supply through wires to the appropriate  
10 feedthrough connections.

A particular ~~arrangement~~<sup>arrangement</sup> of coils may be such that they are arranged in three groups, with the terminations of the coils such that one wire provides the current feed and a second wire provides the current return for each group.  
15 That gives six wires in total for the three groups. A possible array is illustrated in Figure 17C, which shows a plan view of the coil structure and the location of each of the coil groups, numbered 1,2,3 respectively. When a power supply is connected to the pair of wires for the first group  
20 of coils, a uniform magnetic field is created across the processing chamber. Connection of the power supply to the second group of coils with the first disconnected, produces a similar magnetic field but now at a 60 degree angle to that produced by the first group of coils, when viewed along  
25 the axis of the process chamber. Connection of the power supply to the third group of coils, with the other two groups not energised<sup>Z</sup>, leads to a magnetic field that is rotated by a further 60 degrees with respect to the first

group of coils. Therefore, if each group of coils is energized in turn, the magnetic field across the processing chamber will rotate in steps of 60 degrees. A reversal of the polarity of the power supply then allows the field direction to rotate in further steps of 60 degrees as each group of coils in turn is energized. The net effect is a full 360-degree rotation of the field direction as the different coil groups are energized, with the power supply polarity reversed at the appropriate stage. The application of a 3 phase AC power supply to the groups of coils, such that each group is connected across one phase, results in the formation of a magnetic field which rotates at the frequency of the supply.

Although in the above description, the coils are orientated to produce a 60 degree rotation of the field direction when each group in turn is energized, this does not preclude the use of coils orientated to produce larger or smaller angular changes to the direction of the magnetic field. It is not essential that coil groups are energized in a particular order. Therefore the net effect may be a clockwise or anticlockwise rotation of the field or any other sequential or random orientation.

It is desirable to rotate or otherwise alter the magnetic field direction during processing to reduce any non-uniformities in the processing of the substrate due to the influence of the magnetic field on the trajectories of those ions which reach the substrate.

In conclusion, the construction and operation of an ion

attenuator using a number of groups of coils located inside the processing chamber has three potential benefits.

1. The magnetic field across the chamber is more localized<sup>2</sup> in the vertical direction than if coils or permanent magnets were located outside the chamber.
2. The use of coils rather than permanent magnets allows the field strength to be varied during a process; in particular it allows the field strength to be switched between different levels during different steps of a process.
3. The magnetic field across the chamber can be rotated to improve the uniformity of the process, when the magnetic field may influence the directionality of those ions that reach the substrate.